# Predator Effects on Dense Zooplankton Aggregations in the Coastal Ocean

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## LONG-TERM GOALS

The distribution of organisms in the ocean is highly heterogeneous, influencing both sampling and ecological structure. The complex spatial and temporal structure of predators and prey affect one another. Numerous studies in pelagic systems have investigated the effects of prey distribution on predator behavior and studies in benthic habitats have revealed the significant impacts predators can have on prey distribution. However, primarily because of sampling difficulties, few studies have investigated the effects of predators on prey distribution in pelagic systems. In the last decade, advances in measurement capabilities have led to the discovery of plankton aggregations over continental shelves with vertical dimensions of tens of centimeters. These 'thin layers' can have a horizontal extent of several kilometers and may persist for days. Sharply distinct from the surrounding water column, the density of phytoplankton and zooplankton in these layers can be orders of magnitude higher than at surrounding depths. The discovery of these ubiquitous layers of plankton has opened up new possibilities in studying aggregation in the ocean. The long-term goal of this work is to understand the ecological importance of thin layers of plankton

## OBJECTIVES

- Determine the scales of aggregation of acoustic scatterers in the coastal ocean

- Understand the role of predation in determining the scales of these aggregations

- Assess the impact of the interaction of predators with aggregations of prey animals on the performance of acoustical and optical sensors.

## APPROACH

Extremely thin aggregations of zooplankton recently described in a number of coastal systems will be used as the experimental model for addressing these questions. These extremely thin aggregations persist over long time periods, are relatively predictable, and are being intensively studied in Monterey Bay, California as part of the ONR funded Layered Organization in the Coastal Ocean program (LOCO). I will work collaboratively with the investigators of this project to integrate my sampling approach into the existing program, adding a significant new component to the work while leveraging their resources to address the general biological questions of patchiness and scale in predator-prey

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14. ABSTRACT
**The distribution of organisms in the ocean is highly heterogeneous, influencing both sampling and ecological structure. The complex spatial and temporal structure of predators and prey affect one another. Numerous studies in pelagic systems have investigated the effects of prey distribution on predator behavior and studies in benthic habitats have revealed the significant impacts predators can have on prey distribution. However, primarily because of sampling difficulties, few studies have investigated the effects of predators on prey distribution in pelagic systems. In the last decade, advances in measurement capabilities have led to the discovery of plankton aggregations over continental shelves with vertical dimensions of tens of centimeters. These ?thin layers? can have a horizontal extent of several kilometers and may persist for days. Sharply distinct from the surrounding water column, the density of phytoplankton and zooplankton in these layers can be orders of magnitude higher than at surrounding depths. The discovery of these ubiquitous layers of plankton has opened up new possibilities in studying aggregation in the ocean. The long-term goal of this work is to understand the ecological importance of thin layers of plankton**

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interactions that are the focus of my research. The advantage of leveraging this project is the availability of substantial vessel time, supplementary data, and concomitant sensing with other techniques.

*Specific methods:*
Continuously *map the distribution of acoustically scattering thin layers* looking for variations in depth and intensity using a five-frequency split-beam echosounder. Specifically, I will determine where thin layers are absent either through total loss in an area or in small gaps or breaks. Geostatistical techniques will be utilized to characterize the scales of aggregations, their spacing, and the features of edges.

*Compare* the results of synoptic surveys for *acoustically scattering and optically scattering thin layers*. This work will be done in collaboration with B. Concannon and J. Prentice who will be conducting concomitant LIDAR surveys. More than just comparing the two techniques, our goal is to determine if differences in acoustical and optical scattering can be related to the identity or distribution of organisms in these layers. We propose that the combination of optical and acoustic scattering can be used in a way analogous to looking at acoustic frequency spectra and using inverse processing techniques and may provide more information than adding additional frequencies to either technique alone.

Use a series of moored echosounders to *determine if larger scatterers* that may be consumers of organisms within thin aggregations *are regularly present over the shelf* in shallow waters either through advection of diel migrators or through active diel horizontal migration. I will compare the depths of these potential predators to the depths at which thin layers are detected at the same time during ongoing zooplankton process studies. Comparison of changes in the depth of both the thin layers and the larger animals may reveal tracking of the layers by its consumers.

Use a multibeam sonar to *detect relatively large individual, mobile acoustic scatters* both inside and outside thin aggregations of zooplankton. The data will be used to observe their behavior as well as to quantify the intensity and distribution of the thin layer to *determine if these larger animals appear to be foraging inside thin, horizontal layers* and what changes in the layers are correlated with their presence either as an immediate, observable response or statistical difference.

Utilize data to *predict acoustical and optical signal attenuation* as a function of scales of aggregations, their density, and composition. Dense aggregations of organisms can cause significant signal transmission loss and distortion. The variability in biological sources of scattering causes difficulties in predicting these losses. Data from the various approaches will be integrated to understand and predict how predation on dense aggregations can affect signal transmission in the coastal ocean.

## WORK COMPLETED

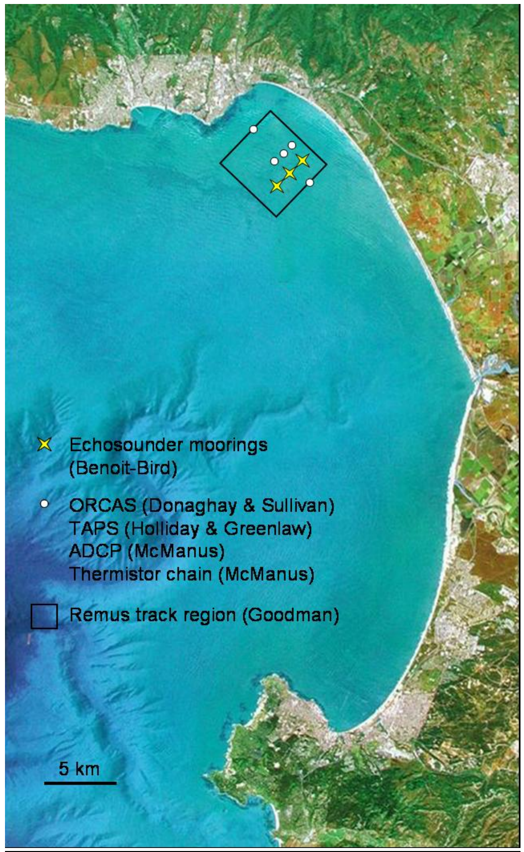


***Figure 1. Map of Monterey Bay showing the location where echosounder moorings were placed in relation to other sampling efforts.***

The first field season for the project was completed in Monterey Bay, California in September, 2005. Monterey Bay along the central coast of California has been identified to have persistent (>7 days) and intense thin aggregations of organisms. The nearshore presence of a deepwater, submarine canyon in Monterey Bay provides a rich source of nutrients through upwelling, making the area highly productive (Graham and Largier 1997). The close proximity of shallow water, nearshore habitat and deepwater, oceanic habitat may permit significant interaction and exchange between the two environments as has been observed in other steep-slope environments (Benoit-Bird et al. 2001) potentially impacting carbon and nutrient cycling as well as measurement capabilities. Because biological layers have been repeatedly observed in Monterey Bay and could play an important role in both coastal and oceanic systems in this area, it made an ideal study site.

Three active acoustic moorings were deployed between August 2 and September 14 2005 (bracketing the cruise) to look for acoustical scattering from micronekton and nekton and the possibility that these predators may be present over the shelf through advection and trapping of diel migrators (Genin et al. 1994; Isaacs and Schwartlose 1965) or through active diel horizontal migration (Benoit-Bird et al. 2001; Omori and Ohta 1981; Sasaki 1914). The onshore movement of predators could be important for the persistence of thin layers of zooplankton and the diel behavior of these animals. Predators like small fish and other micronektonic animals could have cascading effects, releasing phytoplankton from

grazing pressure and indirectly affecting layers of primary producers. Understanding the mechanisms for movement of deep-water, vertically migrating animals into shallow waters is critical for understanding the potential rate of energy transfer from thin layers; how quickly animals aggregated in thin layers are converted to other forms of biomass. For example, if predators are advected into shallow water and then are trapped, these predators will quickly become prey themselves and could facilitate extremely rapid transfer of energy up the food chain in coastal waters. If, however, predators are actively migrating back to deep water, they could be transferring consumed plankton into energy poor, deep waters offshore.

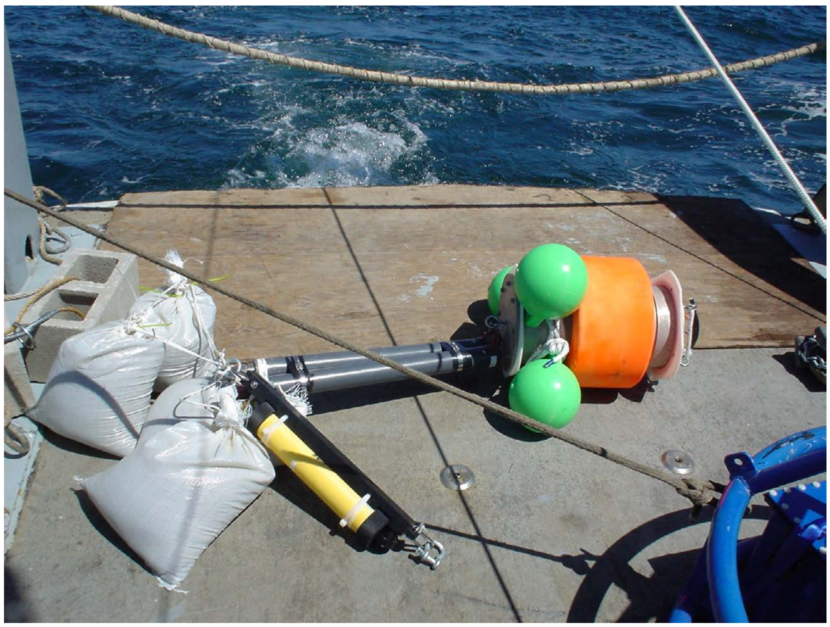

***Figure 2. An echosounder mooring ready for deployment on the deck of the R/V Shana Rae***

Collaboration with investigators who deployed other instruments in this area over the same time period as part of the LOCO program will provide an important physical and biological context for understanding the observed patterns from the active sonar moorings and their importance. The underwater winch profiler (Donaghay and Sullivan, University of Rhode Island), moored acoustic Doppler current profilers (McManus, University of Hawaii), and thermistor chains (McManus) will provide information on physical processes at the site that will help separate the processes underlying inshore predator movement, trapping or active migration. Surveys with a turbulence and fine-structure autonomous underwater vehicle (REMUS, Goodman, University of Massachusetts at Dartmouth) within the study region will describe the finescale sheer and density structure that may directly drive the aggregation of food resources for these predators. Moored Tracor acoustic profiling systems (TAPS, Holliday and Greenlaw, BAE Systems) will describe the distribution of zooplankton in the area. The distribution of larger animals will be compared to the distribution of their potential prey, physical structures, and current patterns.

Between August 17 and September 10, 2005, our research team participated in the LOCO program aboard the R/V New Horizon. Surveys of the horizontal and vertical distribution of sonically scattering organisms were conducted in Monterey Bay, CA . Surveys were conducted at a vessel speed of 1.5 m/s while 600 kHz ADCP data was simultaneously collected by T. Cowles (OSU). We collected survey data from more than 2800 kms within Monterey Bay. We also collected data at 3, 24 hour stations.

Split-beam scientific echosounders operating at 38, 70, 120, and 200 kHz (Simrad EK 60s) and a 710 kHz single beam (Simrad EQ 60) were used to map the distribution of acoustic scattering layers. The use of split beam technology permits measurement of target strength as well as echo integration measurements. Previous studies of thin layers have determined that to effectively detect and characterize thin layers requires a vertical sampling resolution of less than 1 m, which were achieved with all the proposed frequencies.

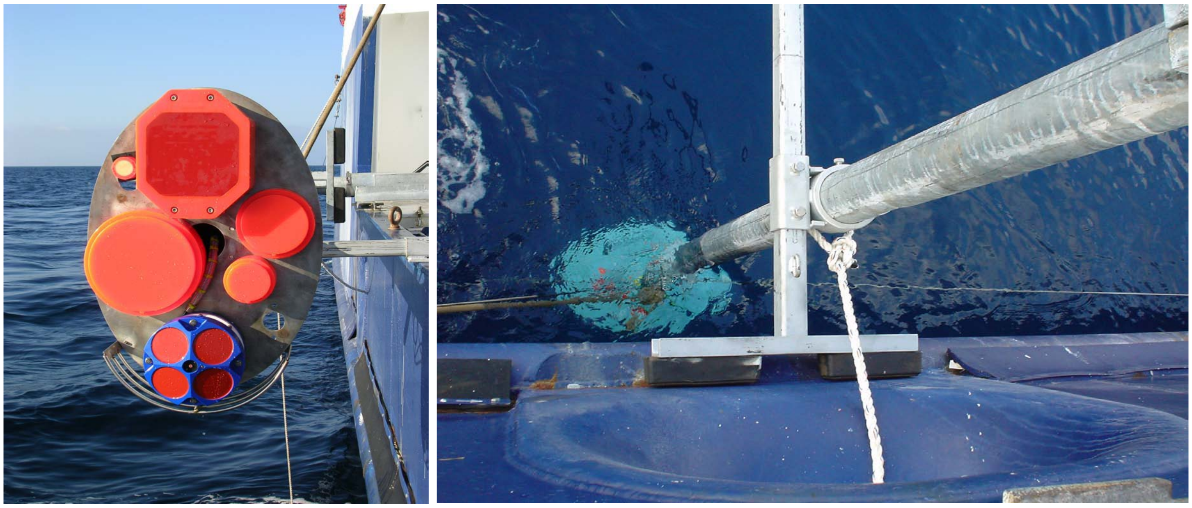

***Figure 3. Five echosounder transducers and the ADCP mounted to the boom (left). Boom in the water (right)***

In addition to ship-based acoustics, acoustic data were collected using the Tracor Acoustic Profiling System (TAPS) mounted to a CTD with a fluorometer. Sixty-nine profiles were made in the study area with the 6-frequency system. This will be important in separating fish and zooplankton scattering. Data from these profiles also provides coherent phytoplankton vertical distribution.

***Figure 4. The CTD frame with TAPS and a fluorometer was used to measure the vertical distribution of phytoplankton and zooplankton.***

The acoustic results will be compared with the vertical profiles made by T. Cowles at the same locations using his “SLOW-Drop” profiler. They will also be compared with B. Concannon and J. Prentice’s (NAVAIR) lidar results. The lidar system mapped optically dense layers while the echosounders mapped acoustically dense layers. Our goal is to compare the returns from each system and to determine the potential of any differences between optically and acoustical scattering to identify the constituents of the scattering layer. This approach is analogous to adding frequencies to an echosounder system or an additional color to lidar. However, because the differences between optical and acoustical scattering are likely to be more substantial than differences between frequencies in an echosounder system, the combination of the two may provide more information than either system can provide alone.

**RESULTS**

Data analysis for this program is just beginning. Preliminary results suggest that zooplankton thin layers were rare inside the study area. However, when phytoplankton thin layers were detected, rapid changes in zooplankton vertical distribution were observed. Further analysis of both the acoustic data and the data collected by other LOCO teams will allow us to explore the behavioral response of zooplankton to phytoplankton.

We found extremely high densities of fish inside Monterey Bay. During the night, fish were dense from 4-6 meters below the surface to 5-7 meters above the bottom. These high densitiy aggregations were extensive in shallow waters (<40 m). Their presence near midnight made acoustical detection of zooplankton from the surface difficult. In addition, they affected other acoustic instruments. For example, the CTD’s altimeter often gave false bottom readings as it approached the fish from above, only giving accurate readings after passing through the fish. The ADCP and the ship’s speed log also gave numerous error messages when fish were identified in these densities. Predators including birds and sea lions were often observed near the boat exploiting the dense resources. The fish identified from their surfacings were primarily sardines. During the day, however, only small schools and diffuse fish layers were detected in our surveys.

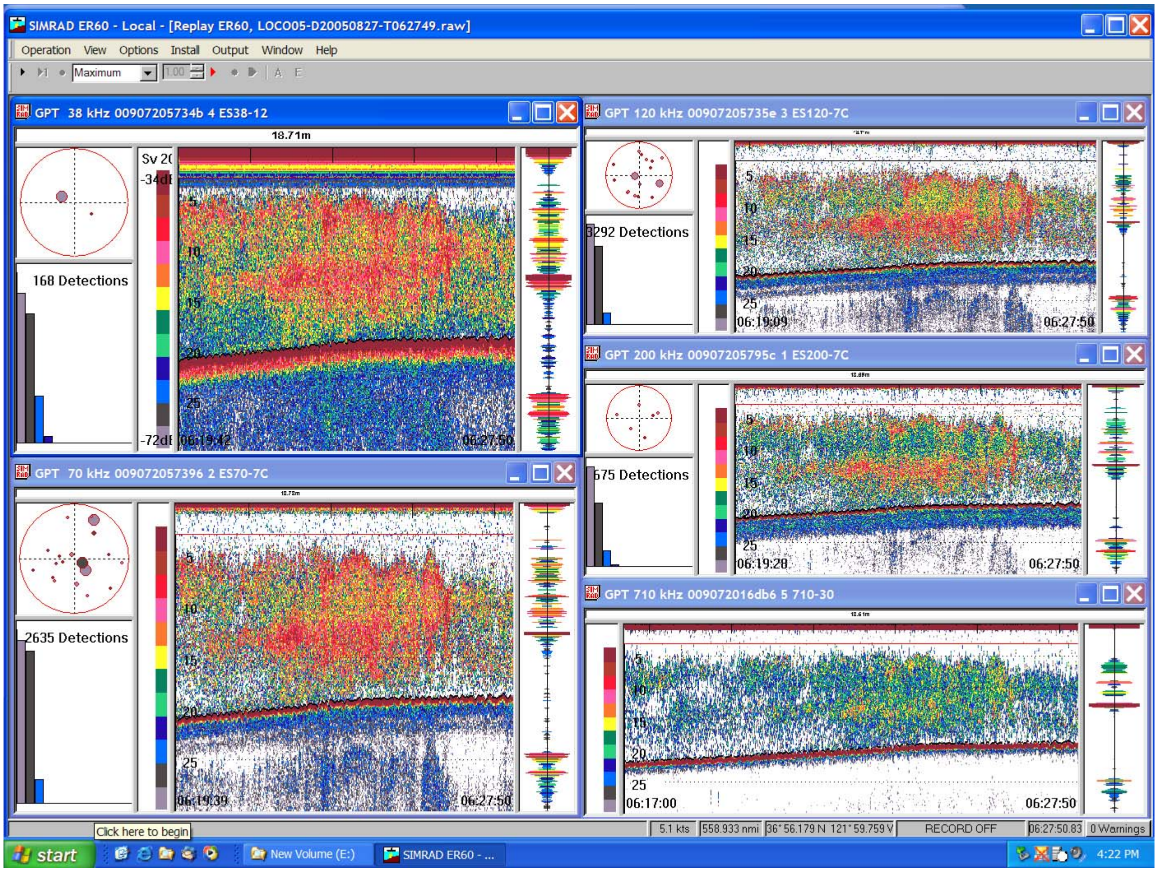


***Figure 5. Image of the real-time display from the 5-frequency acoustic system showing a dense aggregation of fish. The CTD's altimeter was unable to detect the bottom at this location.***

## IMPACT/APPLICATIONS

Patterns in biological distribution are often studied in relation to physical parameters and primary productivity. Numerous studies have demonstrated regulation of plankton by physical oceanographic processes (Denman and Powell 1984; Legendre and Demers 1984). There has been limited research on biological causes of patchiness in the ocean, such as the causes of pattern categorized by Hutchinson (1961): reproductive, interactions between parents and offspring; social, intraspecific signaling between individuals; and coactive, intraspecific actions such as competition, predation and parasitism. This work will provide information on how predators and prey interact in the coastal ocean and will permit us to determine how these interactions affect the formation and maintenance of thin layers. This is critical for understanding how organisms within thin layers affect our measurements and for making predictive models about their distribution. In addition, this work will provide comparable, ship based acoustic surveys for ongoing optical work, giving us a unique opportunity to understand the relationship between acoustical and optical scattering. Combination of these results with direct samples will enable us to integrate acoustical and optical data to examine the possibility of the identifying scattering sources with the synthesized sonar and lidar data.

## RELATED PROJECTS

This project is linked to those that are part of the *Layered Organization in the Coastal Ocean* DRI. Specifically, the projects of Holliday, Cowles, McManus, Prentice and Concannon.

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